Attractive interactions between negatively charged plasma crystal particles
KC 02 01 03

We have, for the first time, measured both the magnitude and shape of the attractive interaction between two negatively charged particles immersed in a plasma. In high school physics, we all learned that two negatively charged particles would always repel each other with a force that increases the closer the particles became to each other. However, for micron and smaller length scales, subtle interparticle interactions can produce attractive forces between negatively charged particles in a plasma that significantly influence the structure and stability of particle assemblies. While our previous 2D, planar plasma crystal assemblies were dominated by repulsive interactions, attractive interactions produced by positive space charge regions are believed to be present in 3D structures. The attractive interaction was directly determined from measurement of extremely low energy head-on collisions between two particles. By manipulating the electric field structure within the plasma, we constructed a type of trough in which the particles collide. We find that the attractive forces are on the order of 10^{-14} N and have an interaction length consistent with our first-principles model. Our direct measurement of the attractive interaction has a significant impact on our understanding of the delicate balance between attractive and repulsive interactions that are critical to the formation of stable 3D particle assemblies in plasmas.

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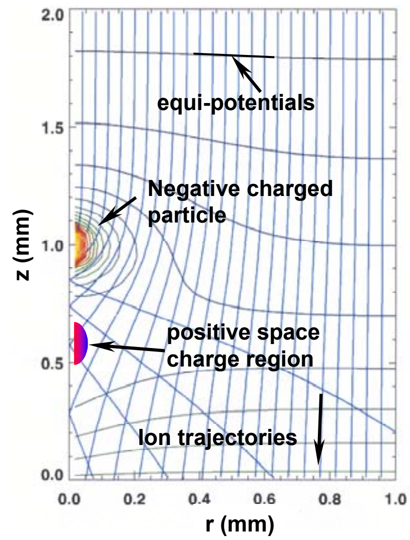
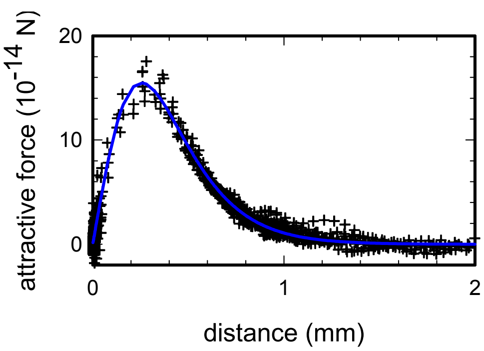
Scientific Accomplishment

For the first time, the attractive interaction between two negatively charged particles immersed in a charge neutral plasma has been measured. In previous work, we demonstrated that the dominant force between particles in a stable 2D planar plasma dust crystal is repulsive. For the case of 3D plasma crystals, additional forces appear to influence the crystal stability. We hypothesize that in 3D assemblies, the structure of the crystals is due to the delicate balance between repulsive Coulomb interactions and attractive forces produced by the motion of positively charged ions around the particles. Our calculations of ion flow past the particles, shown to the right, demonstrated the presence of a significant positive charge region below the particles. That positive space charge region provides the potential for an attractive force between two negatively charged particles.



To characterize the attractive interaction, we developed a new image analysis technique to determine the forces present during very low energy head-on particle collisions. By manipulating the electric fields within the plasma using a parabolic, grooved electrode, a well-defined potential trough is formed. A single particle injected into the trough collides with a second particle sitting stationary in the center of the well. The collision trajectories of the particles are quite complicated and show a number of previously unobserved interactions. An analysis of the particle trajectories as a function of time yields the time dependent forces on the particles. An example of the measured attractive potential and a fit to the functional form predicted by our first principle model are shown on the right. The force was on the order of 100 fN (femtonewtons), comparable to the forces applied by laser tweezers. While the magnitudes of the attractive and repulsive forces are similar, the shape is significantly different than a Coulomb repulsive potential.



Significance

Our measurements of the magnitude and shape of the attractive potential provide new information about the forces present in 3D, charged particle assemblies. When coupled with our first-principles model, we now have critical tools to assess the stability of charged particle assemblies. The low energy collision techniques developed for this work are being applied to force measurements in multi-particle assemblies. We are beginning to incorporate these force potentials into molecular dynamics simulations to predict the time dependent behavior of particle ensembles.

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